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16. ABSTRACT
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Load equivalencies from previous road tests and recent loadometer data are used to determine relative structural damage to pavement by trucks, buses and autos.

Construction costs for asphalt concrete (AC) and Portland cement concrete (PCC) pavements are determined for pavements designed for autos only and for all vehicles, and relative costs are assigned to each category.

Comparison is made on the basis of about 35 years of performance between Arroyo Seco (Pasadena) Freeway, carrying only cars, and three sections of Route 99 carrying all types of vehicles. As a consequence approximately 58% of total pavement cost can be assigned to trucks and buses.

Data from three independent studies regarding the predicted effect of the recent increase in legal loads on the lifetime of pavements are presented.

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AASHO Road Test, asphalt concrete, Portland cement concrete, subgrade, pavement damage, pavement deflection, pavement life, pavement performance, loadometer, axle loads

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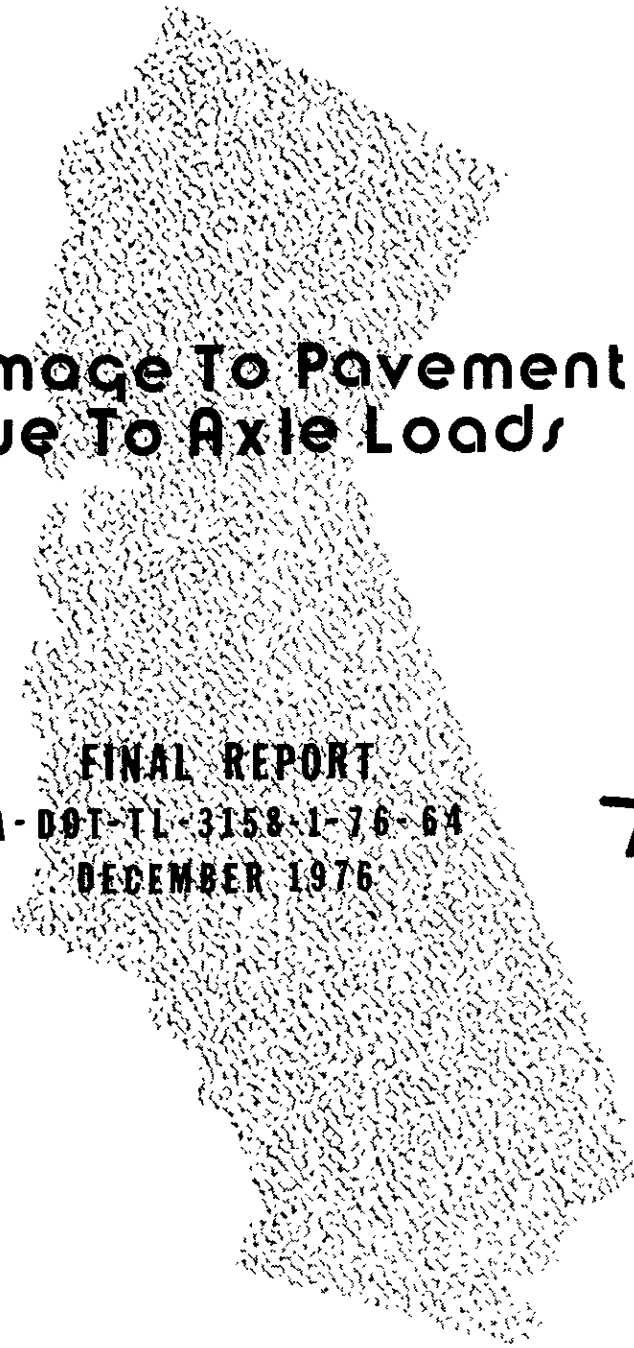
DIVISION OF STRUCTURES AND ENGINEERING SERVICES

TRANSPORTATION LABORATORY

RESEARCH REPORT



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FINAL REPORT

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

December 1976

TL No. 643158

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

DAMAGE TO PAVEMENTS
DUE TO AXLE LOADS

Study made by . . . . Roadbed & Concrete Branch

Under the Supervision of . . . . D. L. Spellman, P.E.

Principal Investigator . . . . J. A. Matthews, P.E.

Co-Investigator . . . . K. L. Baumeister, P.E.

Report Prepared by . . . . J. A. Matthews P.E. &
K. L. Baumeister, P.E.

Very truly yours,

George A Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

KLB:lrb

ACKNOWLEDGEMENTS

The author wishes to thank D. B. Roberts, E. A. Boerger and W. L. Cox for their aid in obtaining the deflection test data and obtaining other pertinent information used in determining predicted service life for various pavements. Credit should also be shared with Roy W. Bushey for his assistance when this project was initiated.

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I. INTRODUCTION

Four methods of comparing pavement damage caused by light vs. heavy axle loads are examined in this study. These four methods are as follows:

1. Pavement deflection measurements,
2. load equivalence data from test roads,
3. pavement cost comparison - (new construction), and
4. pavement performance experience.

Pavement deflection is the temporary vertical displacement of the roadway surface under moving loads. For many years it has been recognized that the magnitude of pavement deflection under load is related to the ability of the pavement to survive under repeated applications of loads (1,2).

The relation between deflection under load repetitions and pavement service life developed by the California Department of Transportation is used to make an approximate comparison between the structural damage done by heavy and light axle loads.

Based on performance data from the AASHO Road Test, which was the most comprehensive performance test in history, and on pavement performance in California, the State's Department of Transportation has developed an empirical relationship between magnitude of axle loadings and the number of applications that can cause pavement fatigue failure. The relationship between damage caused by loads of varying sizes and a "standard" 18,000 lb. axle loading was developed from test road and other data. This known relationship can be used to compute "load equivalence" damage done by mixed traffic as determined from traffic counts and loadometer data. Relative damage to pavement is assigned to trucks, buses and passenger cars on the basis of recent loadometer counts (weight measurements of vehicles using California highways). The load equivalence information, as derived from the AASHO Road Test for both AC and PCC pavements, and data derived from the California method for designing flexible pavements are utilized.

The California design methods for both AC and PCC pavements are also used to compare structural sections designed for passenger cars and other vehicles less than 6,000 lbs. gross load only, to those required for all vehicles. The estimated construction costs of these pavements are used to assess the proportion of total pavement construction cost that can be assigned to trucks, buses, and cars, respectively.

Pavement performance of the Arroyo Seco (now Pasadena) Freeway, which in the past has carried only autos and other light vehicles, is compared to the performance of sections of Route 99 carrying all traffic for a period of approximately 35 years. This comparison is used to provide an estimate of the proportion of total thickness of structural section required for trucks and buses (greater than 6,000 lbs. gross load) for past traffic patterns.

Investigations have been made by California, as well as the federal government (6,8), in an attempt to predict the effect of the recent increase in legal load limits on pavement service life. Information from these studies and one obtained from Great Britain (7) is used to estimate the effect of increased legal load limits on the service life of existing pavements.

II. CONCLUSIONS

1. Based on pavement Deflection Analysis, a light duty roadway selected for this study (0.20' AC over clay material) would withstand about 3,000 passes of an 18,000 lb. axle loading prior to pavement fatigue failure. It was found that pavement surface deflection under the 3000 lb. axle loading was well below critical strain limits for this pavement and would provide a service life not limited by fatigue failure.

2. The Load Equivalence relationship, as developed at the AASHO Test Road for PCC and AC pavements, and California's AC pavement design method show that 1 pass of an 18,000 lb. axle load does about the same pavement structural damage as about 1,850 passes of a 3,000 lb. axle weight or about 34,000 passes of a 1,500 lb. axle load.

3. A cost comparison of pavements designed to serve only light vehicles (less than 6,000 lbs. gross) versus pavements designed to serve the total traffic mix was made for an average State Highway (Traffic Index = 9.0). This comparison reveals that 58% of total pavement construction cost is assignable to vehicles having gross loads in excess of 6,000 lbs.

4. No structural pavement overlays were required to carry only passenger car traffic on Arroyo Seco Freeway for 35 years of service. AC pavements of similar initial thickness (0.6' - 0.7') were constructed, at about the same time, in the lower San Joaquin Valley on several sections of Route 99 to handle the total traffic mix. When actual total thicknesses of AC needed to carry all traffic at the Route 99 locations is compared to the calculated thicknesses required for passenger car traffic only, it is found that an average of 66% of the

total thickness of pavement needed at the Route 99 locations was required to handle the heavier loads imposed by trucks and buses (gross loads greater than 6,000 lbs.).

5. Previous studies (6,8) by the California Department of Transportation and the U.S. Department of Commerce indicate that the proportion of damage to pavements caused by trucks can be expected to increase in the future as a result of an increase in legal load limits.

III. PAVEMENT DEFLECTION APPROACH

An asphalt concrete pavement surface is depressed or deflected under traffic loading. Heavier loads naturally cause greater deflections. A portland cement concrete pavement has much greater slab strength than an asphalt concrete pavement. Deflection of PCC pavements is, therefore, usually small and is not normally used to measure "in-place" strength. However, being more rigid, even small deflections can create high stresses in the concrete which "use up" fatigue life. In the case of AC pavements, surface deflection measurements are utilized as a measure of in-place strength. Low deflections under heavy loads indicate high strength conditions.

In the fall of 1975, three pavement test sections were chosen to obtain a measure of variation in structural strength. These test sections are further described as follows:

Section No.	Location	Description
1	Plymouth Drive (North Highlands)	0.2' AC over clay
2	Rogue River Drive (East Sacramento)	0.2' AC over silty sand
3	El Centro Road (Old State Highway 99 North of Sacramento)	0.3' AC over 0.67' CTB (cement treated base)

Deflection measurements using the Benkelman beam were taken at 30 foot intervals. The loads applied to the pavement varied from 1,500 lb. rear axle load to 20,000 lb. rear axle load. The equipment used and rear axle loads were:

Equipment	Rear Axle Load, lbs.
Dump truck	20K*
Dump truck	18K
Cadillac	3K
Matador	1.5K

The rear axle of the Matador weighed 1,500 lbs. while the Cadillac was loaded to a total of 3,000 lbs. per axle (500 lbs. added) in order to produce a definite difference in deflection readings. The deflection measurements for each type of loading were taken at the same points on the pavement surfaces for each axle loading.

From this data the deflection measurements were then plotted, (Figures 1 through 3) and an evaluated** deflection (d) determined for each loading.

*K = Kip = 1,000 pounds

**80th percentile deflection (third highest deflection of 10 measured deflections)

Section No.	Evaluated** Deflection (d)(.001") Matador 1.5K	Cadillac 3.0K	Truck 18K	Truck 20K	Percent of 18 Kip Deflection Matador	Cadillac
1	8.0	13	56	60	14.3%	23.2%
2	2.5	4.5	23.5	27	10.6%	19.1%
3	1.0	3.0	13	16	7.7%	23.0%
				Avg.	10.9%	21.8%

The 1,500 pound Matador and 3,000 pound Cadillac axle loads produced evaluated deflections that, on the average, were 11% and 22% of those measured under an 18,000 pound loading. The relationship of pavement deflection to pavement "life" is exponential.

Figure 4 is taken from Test Method No. California 356-E. It was developed from pavement deflection criteria based on initial data reported in 1955 and on subsequent investigations of main-line AC pavements with relatively high truck traffic volumes. These criteria were adjusted for variations in traffic loading using laboratory fatigue test specimens cut from various AC pavements. Field research studies of pavement deflection and performance over the last 15 years have verified this relationship. This information has been reported in various HRB and TRB papers.

Deflection measurements under the 18,000 pound axle load on test section No. 1 were on the order of 0.056 inch. Figure 4 indicates this pavement strength to be adequate for about 3,000 repetitions of this loading.

Deflection measurements under the 3,000 pound axle load on this same section of roadway were on the order of 0.013 inch. This level of deflection is well below critical strain limits for this pavement and would provide a service life not limited by fatigue failure.

This comparison shows that the effect of autos on the life of any reasonable pavement design is not a significant factor.

IV. LOAD EQUIVALENCE RELATIONSHIP APPROACH

In California's method of determining the thickness of new pavement structural sections, the equivalent axle load formula developed from extensive AASHO road test data is used (3,4). From this data and from a careful review and correlation with years of accumulated experience, the following empirical formula has been developed:

The number of a vehicle axle load (W_2) passes equivalent to one 18,000 lb. axle load (W_1) pass = $\left(\frac{W_1}{W_2}\right)^{4.2}$

where W_1 = 18,000 lb. truck axle loading
and W_2 = the axle loading being considered.

Using this relationship, it would require $\left(\frac{18}{3}\right)^{4.2}$ or 1,850 of the 3,000 lb. Cadillac axle loads, or $\left(\frac{18}{1.5}\right)^{4.2}$ or 34,100 of the 1,500 lb. Matador axle loads to produce the same load damage to the pavement as a single pass of an 18,000 lb. axle load.

This formula was primarily developed for pavement design for axle loads of 6,000 lbs. to 30,000 lbs. However, sufficient data has been accumulated to validate its use in the lower axle loading ranges.

Figure 5 is taken from "HRB Special Report 73" (4) on the Conference on the AASHO Road Test and shows the load equivalence ratios for various magnitudes of axle weights. This is an exponential relationship. It can readily be seen that axle loads less than 6,000 lbs. would constitute only a small fraction of 18 Kip load in terms of equivalent pavement fatigue damage.

Relative composition of traffic on State highways by various types of vehicles based on 1974-75 California loadometer counts and the relative amount of load damage as determined by load equivalence relationships are indicated in Table 1.

From Table 1, it can be seen that gross loads less than 6,000 pounds are responsible for an insignificant amount of pavement damage.

V. COST COMPARISON OF STRUCTURAL SECTIONS

If the vehicles of a traffic pattern are divided according to vehicles less than 6,000 pound gross load and those heavier than 6,000 pounds, the additional cost of the pavement structural section to accommodate buses and trucks can be determined. It should be pointed out that this analysis applies only to the structural section costs and does not include other costs of a highway such as right of way, cuts and embankments, etc.

Using the typical load count data for an average 2-lane highway, structural section requirements for both asphalt and portland cement concrete pavements were determined for passenger cars, pickups and vans having a gross load of less than 6,000 pounds. Buses and trucks were then added and another structural section was designed based on all vehicles included in the load count (Traffic Index = 9.0). Figure 6 shows both the AC and concrete structural sections required for a moderate volume of traffic considering only the vehicles weighing less than 6,000 pounds, and then considering all traffic. The estimated costs for these pavements based on statewide average 1974 bid prices are also shown. In the cases of both asphalt concrete and portland cement concrete, the cost of the section required for the lighter loads is estimated to be about 42% of the total cost of a pavement section designed for all the traffic. This means about 58% of the total cost of new pavement construction is a consequence of accommodating trucks and buses. If this 58% is divided according to the relative damage done by buses and trucks as shown in Table 1, about 6% of new construction costs would be assigned to buses and 52% would be assigned to trucks over 6,000 pounds gross.

The first signs of failure on multilane highways invariably occur in the outside lanes which generally handle about 85% of the truck traffic. Structural overlays are applied as a repair when needed. The overlay must be carried across the full width of the travelled way because a "step off" at the lane edge is intolerable from a traffic safety standpoint. This adds considerably to the cost of pavement rehabilitation.

Several photos of asphalt concrete pavement, Figures 7 and 8, show the prevalence of damage in the outside freeway lane, which generally takes over 80% of heavier truck traffic for 6-lane freeways and about 90% on most 4-lane freeways. These pictures graphically illustrate the damage done by the heavier loads. The type of failure illustrated is called "alligator cracking" and is due to fatigue, or failure due to repetition of loads and consequent stresses and strains that cumulatively cause failure.

Portland cement concrete pavements are also sensitive to a high number of heavy load repetitions, though damage manifests itself in a different way. Data obtained from the AASHO Test Road (TRB Special Report 73, AASHO Road Test) verify this. The two main kinds of failure observed were cracking and "pumping". Pumping refers to ejection of material from beneath the pavement and its deposition at the pavement edge, or movement of erodable material under the pavement or shoulder resulting in faulted joints.

At the AASHO test road, some pumping occurred in all PCC sections after one million truck axle passes of 6,000 pounds or over. Over one million 2,000 pound single axle loads were applied over concrete pavements as thin as 2-1/2 inches with no significant distress. A concrete pavement this thin, however, is not practical for other reasons.

The concrete pavement structural section (4 inches thick) required to carry the automobiles, pickups and vans that characterize a moderate traffic pattern as shown in Figure 6 is, for practical purposes, the same as a city sidewalk. However, even one passage of a heavy axle load greater than 10,000 pounds could crack this pavement, as is evident in specific locations where transit mix or other heavy trucks cross over sidewalks.

VI. PAVEMENT PERFORMANCE EXPERIENCE

To compare performance of AC roadways carrying different amounts of traffic, sections were selected which will graphically illustrate effect of loading on required pavement structural sections. The first section, the Arroyo Seco Parkway (now Pasadena Freeway), was opened to traffic in 1940. Truck traffic has not been allowed to use this facility throughout its 35-year life. Only recently have buses been allowed to use it. The pavement consists of 6 lanes. The two inside lanes are 0.5 to 0.6 feet AC on one foot of select material or original ground where sandy. The outer lanes are 0.55 to 0.75 feet PCC pavement on one foot of select material or original ground. This facility is carrying traffic volumes from 88,000 vpd (vehicles per day) at its intersection with Route 5 (44,000 in 1946) to 32,000 vpd at its Pasadena end. The PCC has been grooved for skid resistance improvement and is still in excellent condition. The AC has received seal coats to counteract aging and drying but has received no structural overlays. However, the AC has so deteriorated due to aging and drying that it will require some rehabilitation work in the near future. Deterioration of the AC is not due to structural damage by traffic.

Several sections of Route 99 in the lower San Joaquin Valley that have been carrying truck and auto traffic for about the same period of time were chosen for the comparison to the Pasadena (Arroyo Seco) Freeway. These sections of highway were originally constructed of AC pavement having layer thicknesses only slightly greater than the inner lanes of the Arroyo Seco Freeway. A major difference between Arroyo Seco and these other sections of roadway is the heavier loadings imposed by truck traffic on Route 99.

Cores from the AC pavement on the Arroyo Seco Freeway and three Route 99 AC pavements were recently obtained for comparison purposes.

Photos (Figure 9) show the present condition of the AC inner lanes of the Arroyo Seco Freeway. A picture of a pavement core extracted from this roadway is also shown. As previously noted, this pavement was placed about 1940 with no subsequent structural overlay. Figures 10, 11, and 12 show the present condition of pavements at three locations on Route 99, including pictures of pavement cores taken for comparison purposes. It should be noted that while no overlay repairs were required to carry only passenger car traffic on Arroyo Seco Freeway for 35 years, substantial overlays were required at all three Route 99 locations to accommodate the heavier loadings of trucks for about the same period of time.

At two of the three Route 99 locations, it can be seen that the pavement thickness required to accommodate all traffic, especially truck traffic, is about twice the original pavement thickness at Arroyo Seco, which has carried only passenger car traffic. The third location, represented by Figure 11, is old Route 99 through the City of Selma. This roadway was relinquished from the State to the City in 1965 and it has been carrying lighter traffic loadings for the past ten years. It also has much more stable subgrade support and therefore requires less pavement thickness than at the other locations.

The major factors affecting the required pavement thickness are (1) subgrade support strength, and (2) traffic loads. These factors are commonly expressed in standard terms or measurements such as R-value to measure subgrade strength, and number of passes of equivalent 18,000 pound axle loads as a measure of traffic. These measurements were collected from all four highway locations to permit a direct comparison. Traffic data used was cumulative auto traffic to date (1975) with the exception of Route 99 at Madera, where traffic data to 1973 (when last overlay was placed) was used. All of these pavements except the Madera section are in need of rehabilitation in the near future. Table 2 was prepared to indicate how pavement thickness requirements to carry all vehicles at the three Route 99 locations compare to the design thickness required to accommodate only passenger cars as determined from traffic records. The additional thickness (Column F) required for vehicles greater than 6,000 pounds gross was determined by subtracting the thickness required for autos only from that needed for all traffic. The average increase in thickness required was 66%, of which 60% can be assigned to trucks and 6% to buses based on the relationship in Table 1.

Use of the California structural design method previously indicated that 58% of the cost of the structural section (new construction) can be assigned to vehicles over 6,000 lbs. gross weight. When long-term pavement costs are also considered, the apparent increase is mainly due to the fact that, in the interest of economy, new AC pavements are normally designed on the basis of a predicted lifetime of 20 years, with additional AC pavement, the most expensive structural section element, being placed later, when required.

VII. EFFECTS OF INCREASED LEGAL LOAD LIMITS

Studies of the effect of increasing the legal load limit from 18,000 to 20,000 pounds for single axles and from 32,000 to either 35,000 or 36,000 pounds tandem axles were made by the California Transportation Department and the Federal Government as well as other public agencies (6,7,8). According to a study by R. E. Smith in July 1973 (8), if half those trucks which hauled legal limit loads were to increase axle loads to the proposed limits, the decrease in fatigue life of existing pavements is predicted to be between 20 and 25%.

In the Federal study (6), estimates were made of the average remaining lifetime of the existing pavements in various states under existing load limits, and for limits of 20,000 single axle and 35,000 tandem axles. For California, the average remaining pavement life for these two conditions were predicted at 10.5 years and 8.6 years, respectively, or an average decrease in life of 18%.

A study was also made in Great Britain (7) regarding the effect on construction and maintenance costs for an increase in the legal load limit in that nation. The decrease in lifetime of a pavement prior to overlay repair was estimated to be about 19% for an increase of legal loads of 11% (equivalent to an increase of single axle load from 18,000 to 20,000 pounds).

Findings from these three independent studies indicate that an 11% increase in legal load limits appears to reduce service life in years approximately 20%.

Recent legislation by Congress (1975) permitted loads of 20,000 lb. single axle and 34,000 lb. tandem axle loadings on the Interstate Highway System. This is about an 11% increase in loading for single axle and approximately a 6 1/4% increase for tandem axle loads.

The effect of this decrease in pavement life will be to increase maintenance costs on existing pavements considerably over what they have been in the past and require reconstruction and rehabilitation at an earlier date.

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TABLE 1

STRUCTURAL DAMAGE TO PAVEMENTS

	Distribution of California Vehicles* % of Total Vehicles	% Damage to Pavement (from load equivalence Relationship)
Passenger cars (under 6000# gross)	77.5	.3
Panels & Pickups (under 6000# gross)	13.0	0.2
Buses (over 6000# gross)	.5	10.5
Trucks (over 6000# gross)	9.	89.

*Based on 1974-75 Loadometer Data

For explanation of table see example on following page.

TABLE 2

Section	A No. Cars ($\times 10^6$)	B EALs* ($\times 10^6$)	C R-value of Subgrade	D Pavement Thickness Required for Cars**	E Total Thickness Placed for All Traffic***	F Additional Thickness Req'd for Vehicles> 6000# Gross	G % Total Thickness Req'd for Vehicles >6000# Gross	
Arroyo Seco (pasadena Fwy) (inner lane)	62	0.025	25	0.58'	0.58'	---	---	
Union Ave. Old Rt 99 near Bakersfield (outer lane)	20	0.008	32	0.44'	1.13'	0.69	61	
Rt 99 in Madera**** (outer lane)	38	0.015	60	0.29'	0.89'	0.60	67	avg. 66%
Old Rt 99 in Selma (outer lane)	32	0.013	70	0.22'	0.75'	0.53	71	

*Equivalent 18,000# axle loads due to cars
**Using California current Design Equation
***Thickness from cores
****All data for this project applies to pavement in 1973 before last overlay

PAVEMENT THICKNESS REQUIREMENTS

Explanation of Table 2

Example of Determination of Design Thickness

Thickness nessed for cars only (D in Table 2)

(1) Thickness or D = $\frac{0.0032(TI)(100-R)}{G_f}$

(from Calif. Highway Design Manual)

where D = Thickness of AC needed to carry autos only
TI = Traffic Index
R = R-value of subgrade
G_f = Gravel factor for asphalt concrete

Example for Union Ave:

20×10^6 cars over 35+ years service
R-value subgrade = 32
G_f or Gravel Factor = 2.5 $\sqrt{\frac{5.14}{TI}}$

(2) $TI = 9(\frac{EAL}{10^6})^{0.119}$

(from Calif. Highway Design Manual)

where EAL = Equivalent 18,000# Axle Loads = 0.0004* x (No. Cars)
= $0.0004 \times 20 \times 10^6 = 0.008 \times 10^6$

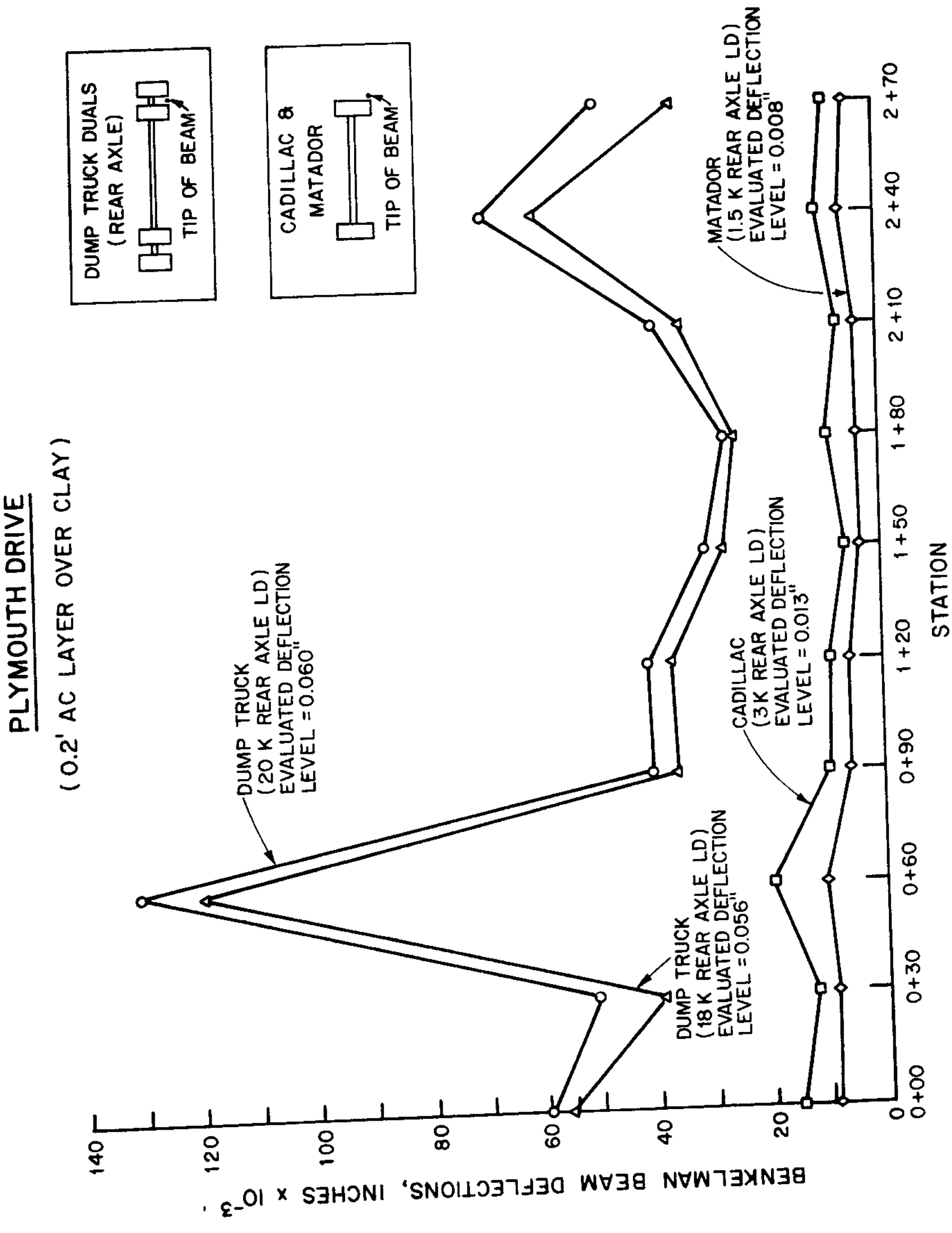
then $TI = 9(0.008)^{0.119} = 5.07$

From Equation (1), thickness or D = $\frac{0.0032(5.07)(100-32)}{2.5}$ = 0.44 feet

Actual AC thickness placed at this location to carry total traffic including cars was 1.13 ft. Additional thickness needed for traffic other than cars, vans and pickups is therefore 1.13 - 0.44 or 0.69'. In this case heavier traffic loads required about 2-1/2 times as much thickness as cars alone.

*Derived from auto registration data (Automotive News, 1975 Almanac Issue) and equivalence factors (The AASHO Road Test - H.R.B. Special Report 73).

**From Test Method No. Calif. 301.


PLYMOUTH DRIVE
(0.2' AC LAYER OVER CLAY)
DUMP TRUCK DUALS
(REAR AXLE)
TIP OF BEAM
CADILLAC &
MATADOR
TIP OF BEAM
DUMP TRUCK
(20 K REAR AXLE LD)
EVALUATED DEFLECTION
LEVEL = 0.060"
DUMP TRUCK
(18 K REAR AXLE LD)
EVALUATED DEFLECTION
LEVEL = 0.056"
CADILLAC
(3K REAR AXLE LD)
EVALUATED DEFLECTION
LEVEL = 0.013"
MATADOR
(1.5 K REAR AXLE LD)
EVALUATED DEFLECTION
LEVEL = 0.008"
0
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120
140
BENKELMAN BEAM DEFLECTIONS, INCHES x 10^{-3}
0+00
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0+60
0+90
1+20
1+50
1+80
2+10
2+40
2+70
STATION

FIGURE 1

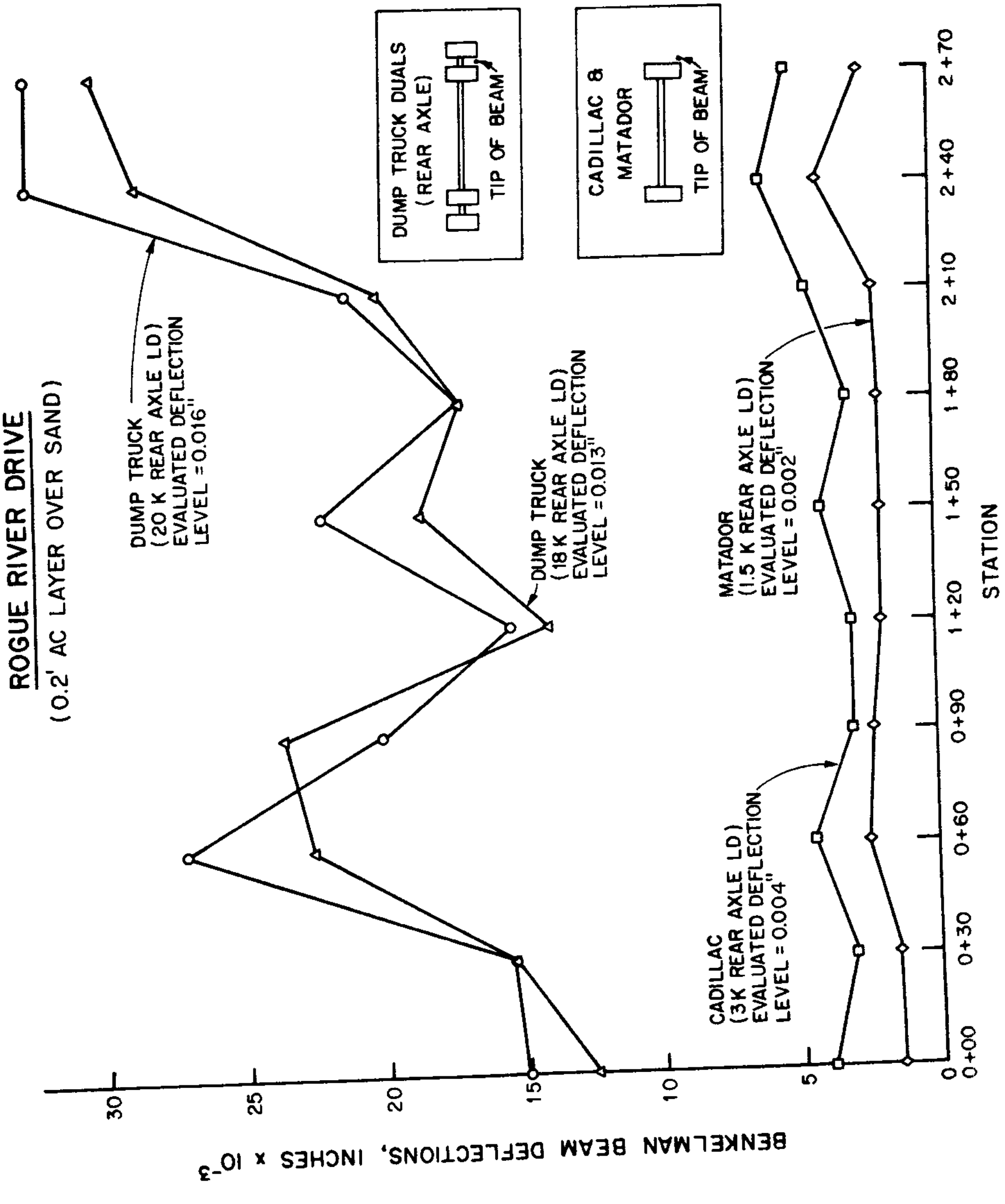

ROGUE RIVER DRIVE
(0.2' AC LAYER OVER SAND)
DUMP TRUCK DUALS (REAR AXLE)
TIP OF BEAM
CADILLAC & MATADOR
TIP OF BEAM
DUMP TRUCK (20 K REAR AXLE LD) EVALUATED DEFLECTION LEVEL = 0.016"
DUMP TRUCK (18 K REAR AXLE LD) EVALUATED DEFLECTION LEVEL = 0.013"
MATADOR (1.5 K REAR AXLE LD) EVALUATED DEFLECTION LEVEL = 0.002"
CADILLAC (3 K REAR AXLE LD) EVALUATED DEFLECTION LEVEL = 0.004"
BENKELMAN BEAM DEFLECTIONS, INCHES x 10^-3
STATION
0 5 10 15 20 25 30
0+00 0+30 0+60 0+90 1+20 1+50 1+80 2+10 2+40 2+70

FIGURE 2

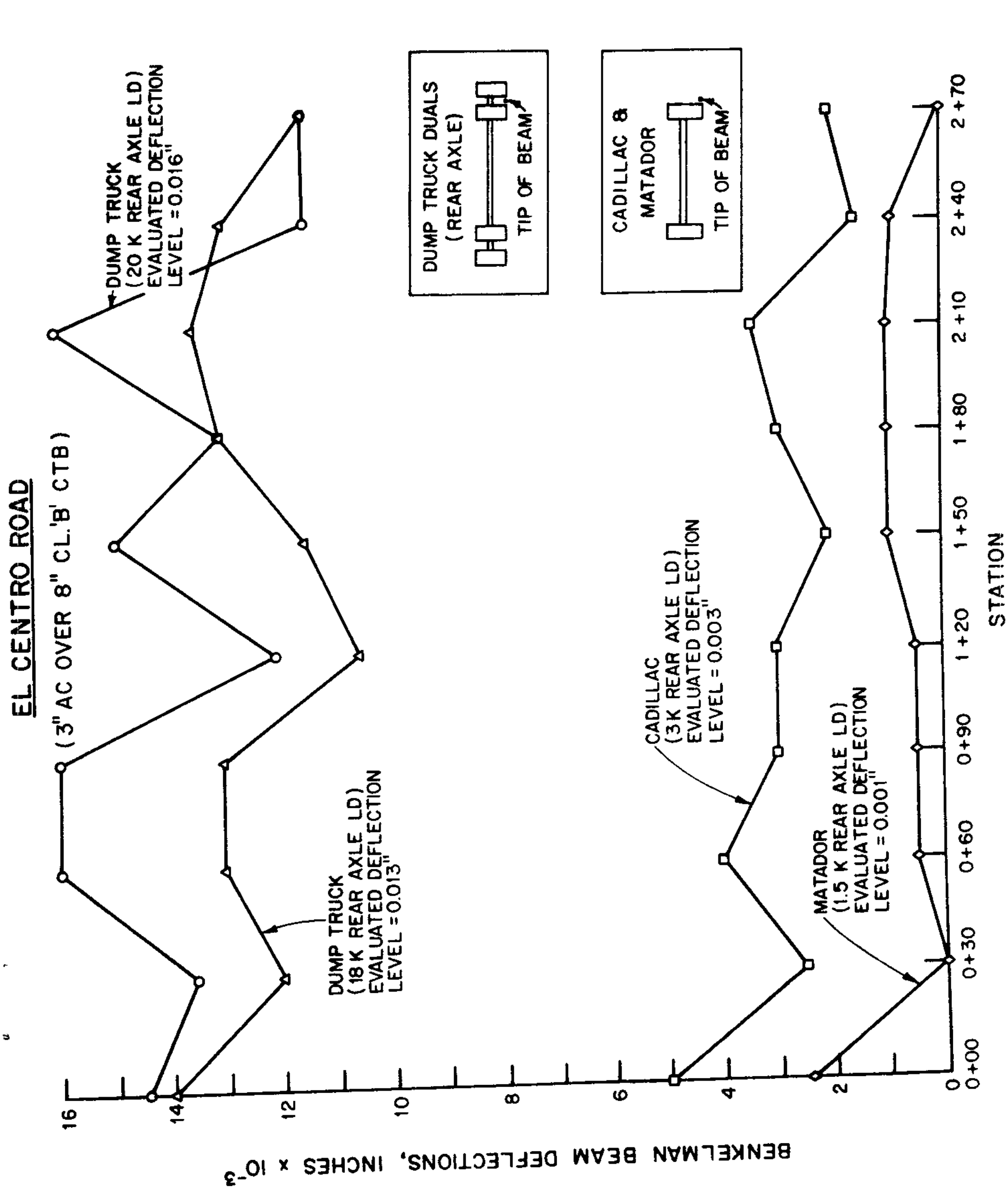
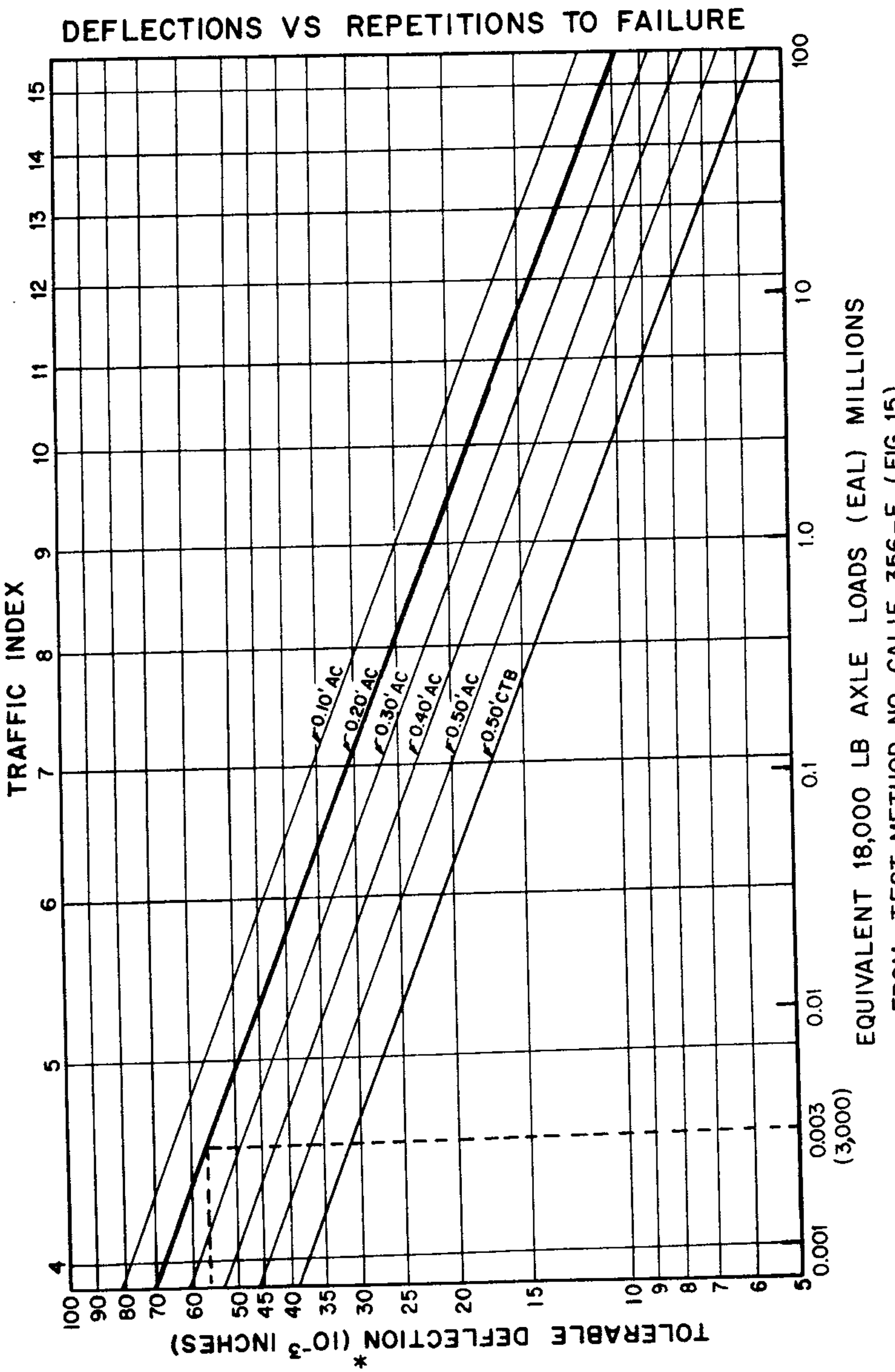

EL CENTRO ROAD
(3" AC OVER 8" CL.'B' CTB)
DUMP TRUCK
(20 K REAR AXLE LD)
EVALUATED DEFLECTION
LEVEL = 0.016"
DUMP TRUCK DUALS
(REAR AXLE)
TIP OF BEAM
CADILLAC &
MATADOR
TIP OF BEAM
DUMP TRUCK
(18 K REAR AXLE LD)
EVALUATED DEFLECTION
LEVEL = 0.013"
CADILLAC
(3 K REAR AXLE LD)
EVALUATED DEFLECTION
LEVEL = 0.003"
MATADOR
(1.5 K REAR AXLE LD)
EVALUATED DEFLECTION
LEVEL = 0.001"
BENKELMAN BEAM DEFLECTIONS, INCHES x 10^-3
16
14
12
10
8
6
4
2
0
STATION
0+00
0+30
0+60
0+90
1+20
1+50
1+80
2+10
2+40
2+70

FIGURE 3



TOLERABLE DEFLECTIONS* FOR ASPHALT CONCRETE

* EVALUATED DEFLECTION LEVEL (80th PERCENTILE) IS USED

FIGURE 4

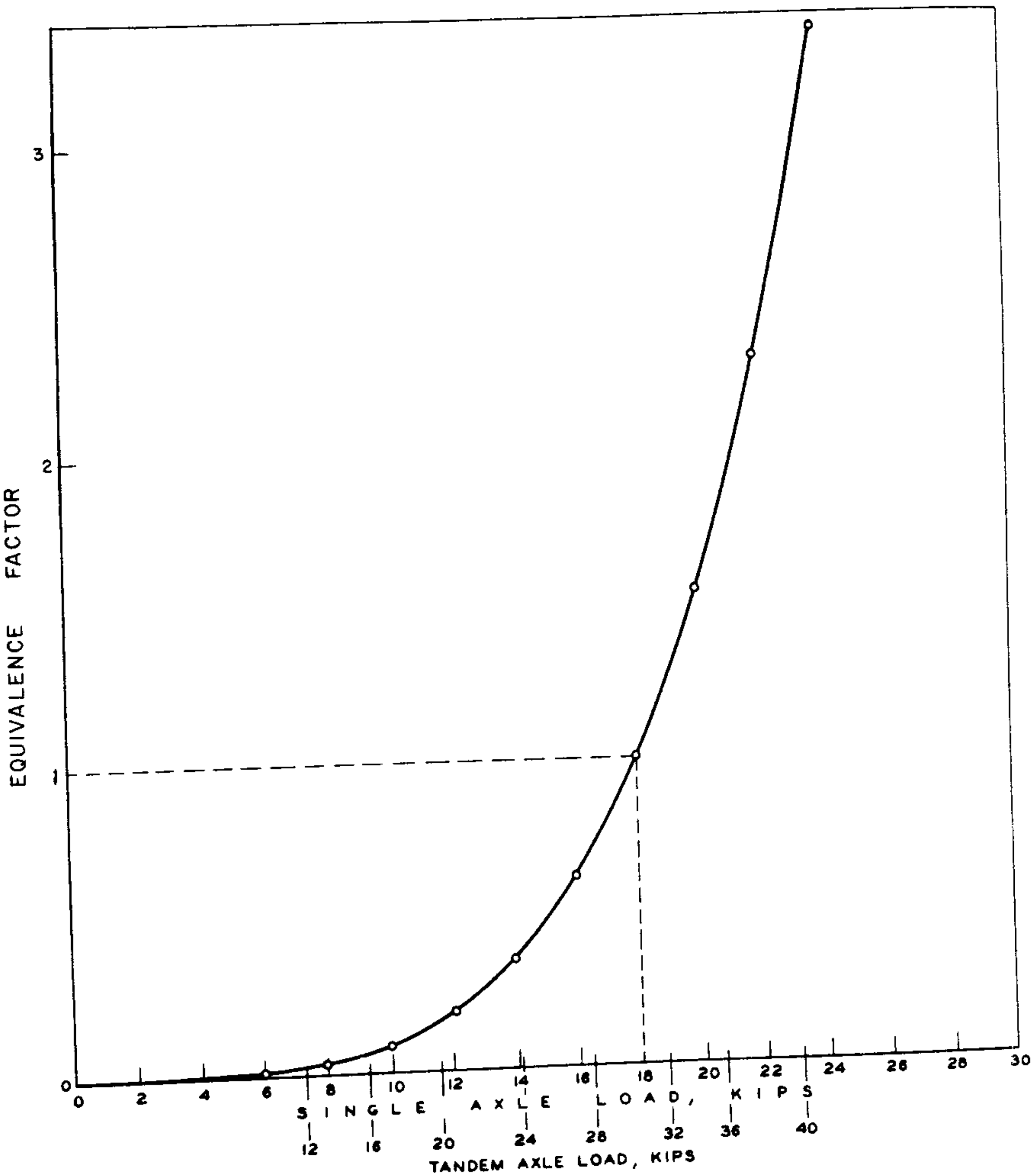
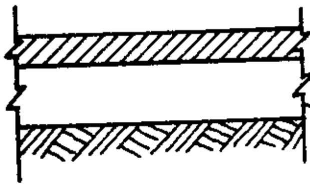


Figure 5. Relation between axle loads and equivalence factors, based on terminal serviceability index of 2.2, and on average equivalence factors for both rigid and flexible pavement.

FIGURE 5

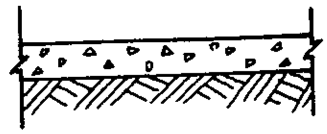
TYPICAL STRUCTURAL SECTIONS AND CONSTRUCTION COSTS*

A.C. PAVEMENT



$23,000 per Lane Mile

PCC PAVEMENT



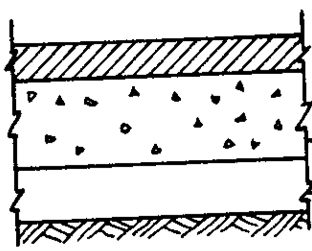
$25,000 per Lane Mile

TO ACCOMMODATE

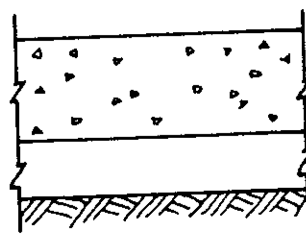
AUTOS, PICKUPS & VANS ONLY

TI = 4.8 (<6,000# gross wt.)

AVERAGE COST = $24,000/lane mile



$54,000 per Lane Mile



$60,000 per Lane Mile

TO ACCOMMODATE

ALL TRAFFIC

TI = 9.0

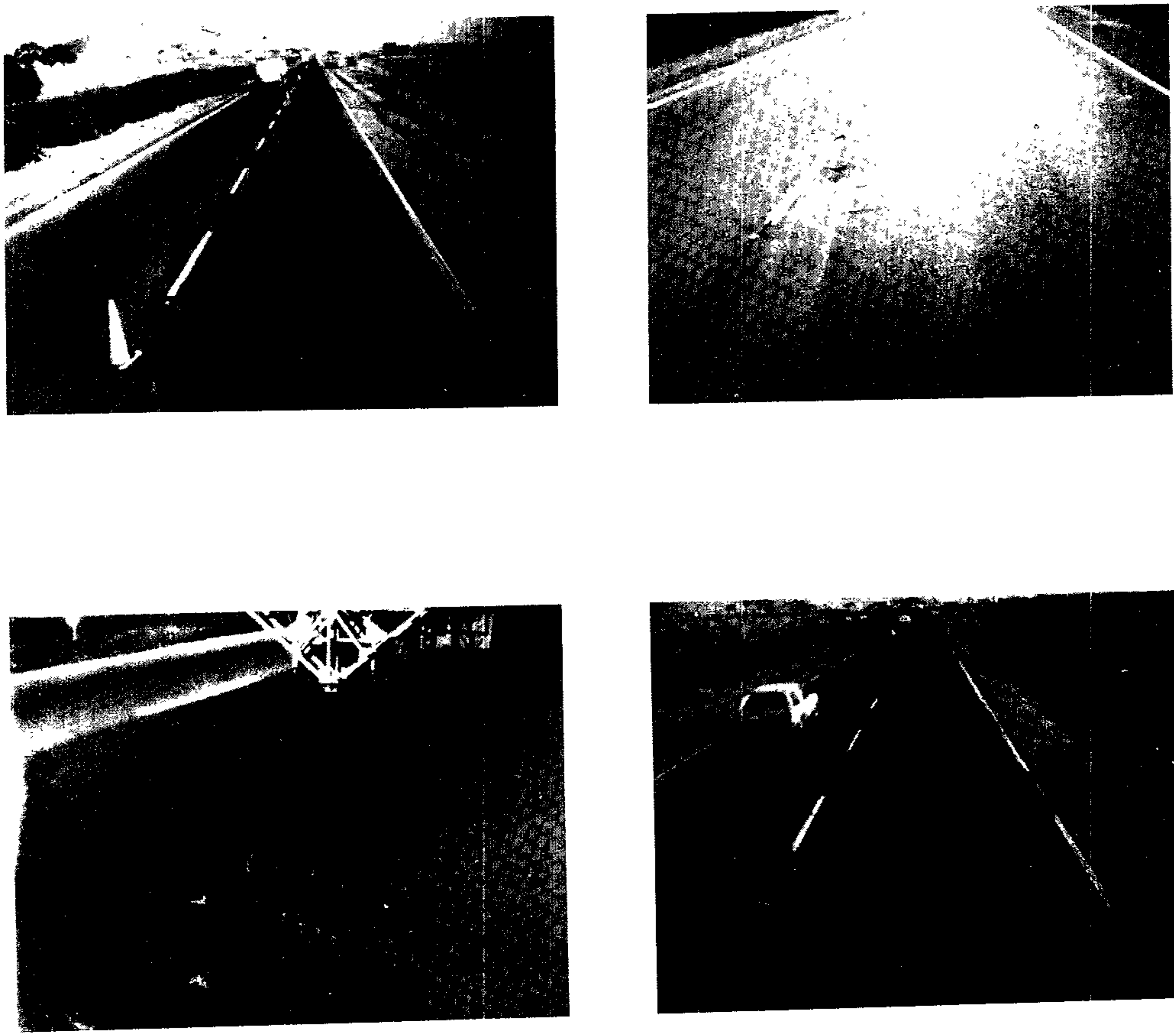
AVERAGE COST = $57,000/lane mile

ASSIGNMENT PAVEMENT CONSTRUCTION COST:

Type Vehicles	A.C. Pavement	P.C.C. Pavement
Autos, Pickups, Vans (<6,000# gross)	42.5%	41.7%
Trucks & Buses	57.5%	58.3%

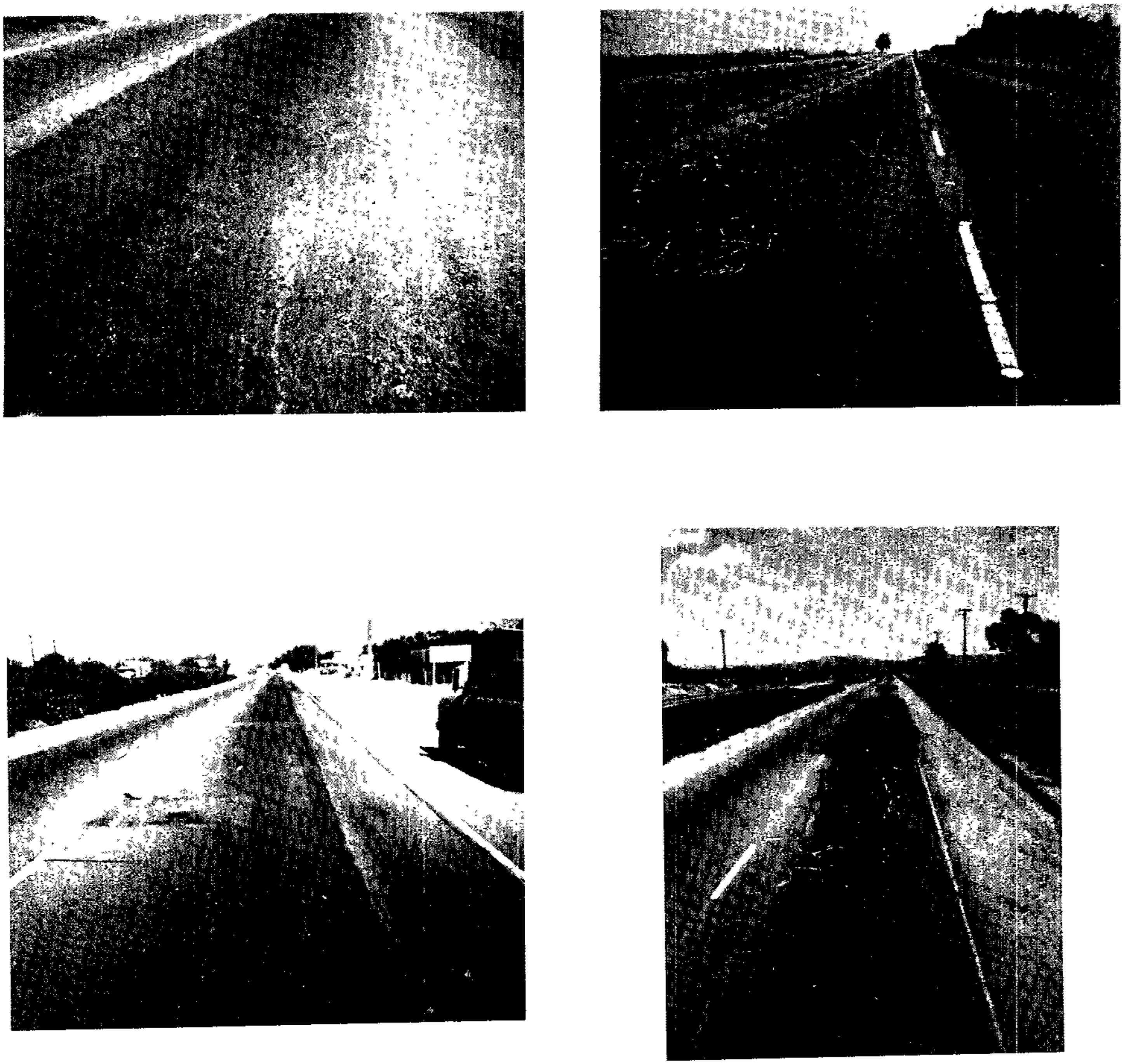
*Based on 1974 Avg. Bid Prices

FIGURE 6



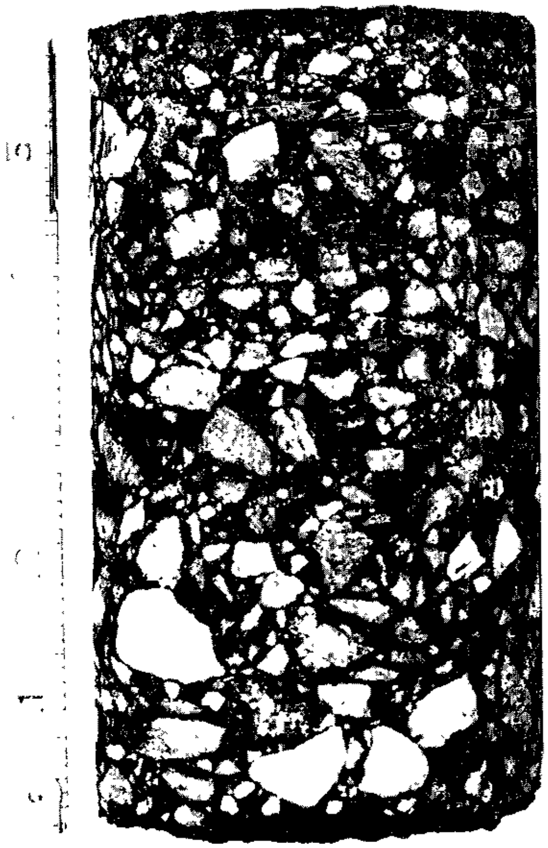
Typical Structural Failures on 4-Lane Freeways

FIGURE 7



Typical Structural Failures on 4-Lane Freeways

FIGURE 8



OLD ARROYO SECO FREEWAY

1974 ADT, 88,000 at Rte 5

32,000 at Pasadena

0.58' AC 1940
With no subsequent overlay

Has been carrying auto traffic only since 1940

FIGURE 9

EXISTING RTE 99 SOUTH OF MADERA

1974 ADT = 24,800

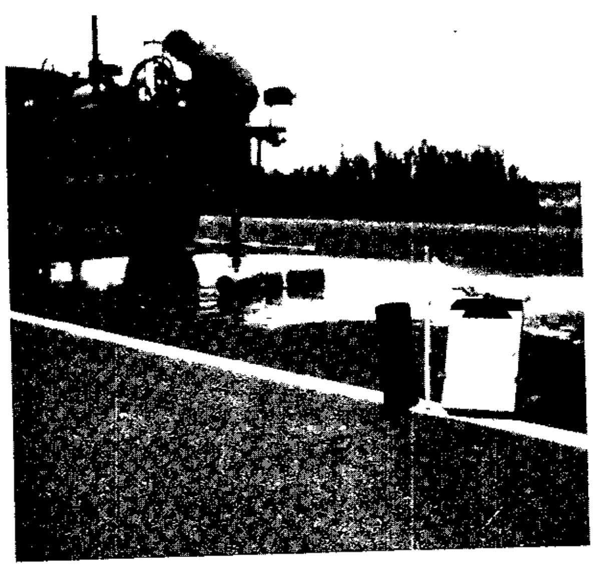
0.15' A.C. 1973

0.17' A.C. 1967

2 Chip Seals = 0.04'

0.60'-0.75' A.C. (Avg. 0.68' A.C.) 1941
Opened to traffic 1941. Has been carrying trucks, buses, and autos since 1941

1.04' A.C. Total Depth



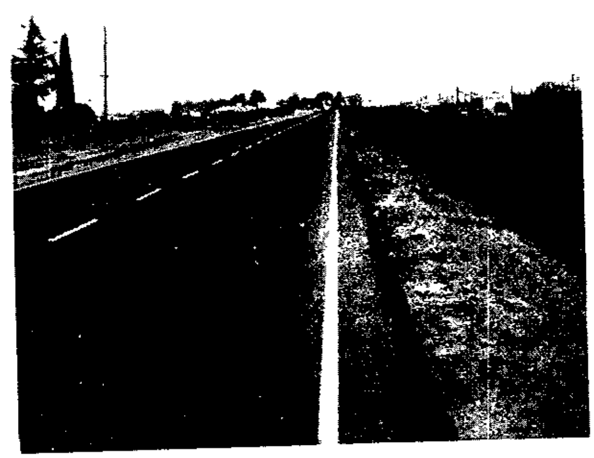
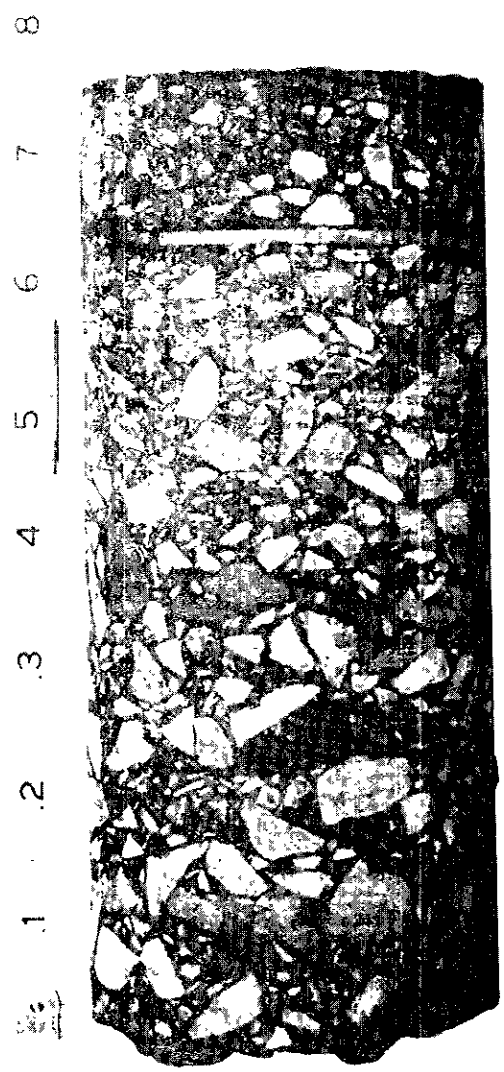


FIGURE 10



OLD RTE 99 IN SELMA

(Now a city street)

1975 ADT = 4,000

0.15 A.C. Relinquished to Selma in 1965 - 1964 ADT = 20,000

0.60' A.C. 1938
Opened to traffic 1938
Has been carrying trucks, buses and autos since 1938

0.75' A.C. = Total Depth

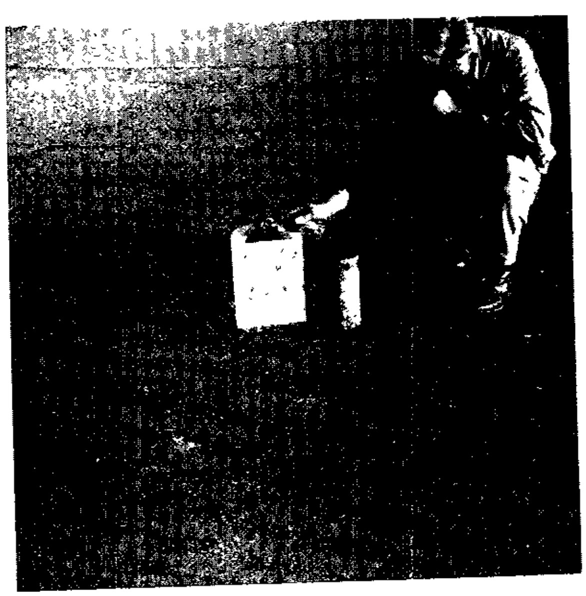


FIGURE 11

UNION AVE (OLD RTE 99)

1974 ADT = 3,400

0.08' A.C. 1964 - Rte 99 relinquished to Kern Co. in 1964

1962 ADT = 14,000

0.20' A.C. 1957
Has been carrying trucks, buses and autos since 1938

0.25' A.C. 1948

0.60' A.C. 1938, opened to traffic 1938

1.13' A.C. = Total Depth

FIGURE 12